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THE APPLICATION AND MEASUREMENT OF ARTIFICIAL RAINFALL ON THE TYPES FA AND F INFILTROMETERS

H. G. Wilm, Lowell Woodward, & Bert G. Goodell

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May 25, 1942

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THE APPLICATION AND MEASUREMENT OF ARTIFICIAL RAINFALL ON THE TYPES FA AND F INFILTROMETERS

By

H. G. Wilm, Lowell Woodward, and Bert C. Goodell

Fort Collins, Colorado

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THE APPLICATION AND MEASUREMENT OF ARTIFICIAL RAINFALL ON THE TYPES FA AND F INFILTROMETERS

By

H. G. Wilm,[1] Lowell Woodward,[2] and Bert C. Goodell[2]

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INTRODUCTION

In field use of the Types FA and F infiltrometers, some difficulties have been experienced in the consistent and uniform application and accurate measurement of artificial precipitation. Because consequent inaccuracies in computed infiltration rates were undesirably large, we were directed to work out improvements in existing equipment and to test a number of methods for measuring rates of water applied with the improved instruments. Accordingly, with a tentative working plan [3] and a number of written suggestions from various sources to serve as guides, studies were organized to accomplish three main objectives:

1. To review all practical suggestions for the improvement of both instruments, and to incorporate them into the existing infiltrometers so as to provide instruments as free as possible of ordinary inaccuracies in water application;

2. To test the shape and stability of rainfall patterns applied with the improved equipment, and to estimate the effect of variations in plot-slope and rainfall rate upon pattern shape and stability; and

3. To evaluate the merits and accuracy of several methods of measuring rates of rainfall, and to show how the accuracy of selected methods is affected by variations in plot slope, rainfall rate, and other factors.

These studies were conducted at Fort Collins, Colorado, during March and April, 1942. [2]

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[1] Silviculturist, Rocky Mountain Forest and Range Exp. Sta. (maintained by Forest Service, U. S. Dept. of Agric., in cooperation with Colorado State College of Agriculture and Mechanic Arts, Fort Collins, Colorado).

[2] Junior Foresters, Intermountain Forest and Range Exp. Sta.

[3] Working Plan, Infiltrometer Study, Part I, by R. A. Hertzler.

PAST WORK AND STATUS OF INSTRUMENTS

Type FA Infiltrometer

The North Fork (now Type FA) infiltrometer was first designed by P. B. Rowe of the Forest Service. Through a rapid evolution it was subsequently developed, largely by flood control survey workers, into the present Type FA infiltrometer. As used on flood-control surveys, this instrument consists of a metal plot frame 12x30 inches in size, with one end adjustable to keep its projected length constant on various slopes. Rainfall is applied by one or more Type F sprinkler nozzles, to provide intensities from about two to about six inches or more per hour. Ordinarily, intensities fluctuating around two or four inches per hour are employed, depending on the infiltration capacities of the soils studied. The rates of water applied are measured by covering the whole instrument with a pan 12x30 inches in size and making a 10-minute calibration run before and after each infiltration test. Because of fluctuations in rate of application, it was thought that this method might not give a reliable index of the true rates applied during the test. Also, as the present pan is only $1\frac{1}{2}$ inches in depth, some of the water applied during each calibration run might be lost by splashing.

A. L. Sharp of the Soil Conservation Service has made detailed studies of this instrument and the Type F infiltrometer, in an effort to refine instrumental techniques. Some of his conclusions reflect rather seriously on the performance of the present FA equipment. He believes, for example, that the normal working pressure (15 pounds) may be critical for the Type F nozzles, so that excessive fluctuations in rate of application may occur, even with a uniform pressure. A working pressure of 25 pounds has been suggested; if this were employed the height, angle, and position of the nozzles should be altered considerably with relation to the plot, so as to give approximately the present drop-fall distance and uniform rainfall patterns. Sharp has also suggested the use of two nozzles, so that nozzle variations might tend to compensate each other. With any suggested pressures or other revision, however, he apparently feels that substantial variations in rate of application must be expected, and therefore that rainfall should be measured during each actual infiltration test rather than before and after it. Finally, Sharp states that the use of a water meter to measure rates of application is of little value. Since the area sprinkled is much larger than the plot, and since the rainfall pattern drops off rapidly toward its edges, slight variations in location of the pattern result in measurable changes in rainfall intensity on the plot, even though delivery through the meter is held constant.

In tests at the Rocky Mountain Forest and Range Experiment Station, Wilm has found that eight 1-inch cylindrical rain-gages hung over the Type FA instrument gave average rainfall rates per 20-minute period agreeing quite closely with the catch in the pan. In the course of this work, a sprinkler frame was designed which places the nozzles rigidly in their proper position in relation to the plot. Optimum rainfall patterns were obtained by the use of two nozzles, placed the same distance above the plot rather than in a horizontal plane, and with each nozzle at a 7° angle

toward the plot and vertical in the other plane. In field studies using this sprinkler arrangement, no significant variations in rainfall pattern resulted from large variations in ground slope (from 3 to 40 percent).

Sharp recommends the use of a pressure-regulating valve and surge tank to maintain uniform pressures. Wilm, on the other hand, has found that uniform pressures may be maintained by using at least 50 feet of 1½-inch fire hose between the pumping unit and the 1-inch infiltrometer hose, with a throttling valve located just below (away from the infiltrometer) a pressure-gage mounted on the sprinkler frame. With a pressure of roughly 25-30 pounds in the main hose and 15 pounds at the gage, the fire hose serves as an efficient surge tank.

Both Sharp and Wilm have found the standard adjustable infiltrometer frame to be awkward in use, and have employed a frame of fixed dimension, 12x30 inches in size. As a result, the slope length of the plot is constant, and the projected length varies little over a wide range in slopes (cos 20° = 0.9397, for example). C. H. Diebold and others have suggested that the frame be made 12x30½ inches in dimensions, so that 1 cc. of runoff per minute will equal a rate of 0.01 inch per hour. Hertzler and others have pointed out that, in the standard infiltrometer frame, some rainfall may enter the runoff trough directly, and have suggested that the frame be revised to eliminate the resulting direct runoff.

Type F Infiltrometer

This instrument, designed by the Soil Conservation Service, has also been used extensively in flood-control surveys. It consists of a plot frame 6x12 feet in size, with runoff measured through a Type HS flume and rainfall applied by means of 14 Type F nozzles, 7 on each side of the plot. Rates of rainfall application are measured before and after each test by a 10-minute calibration run, with a canvas tarpaulin hung over the plot frame.

Sharp has found rainfall application to be quite satisfactory for this instrument; under optimum conditions calibration runs will agree within 0.01 to 0.02-inch of rain per hour. He states that the calibration pan or tarpaulin must be shielded by a splash screen of 16-18 mesh wire for at least one foot from the edges, to prevent splash; otherwise, measured intensities may be in error from 1 to 3 percent.

Wilm has found that two 1-inch trough rain-gages, each 12 feet long, hung over the plot so as to bisect each longitudinal half of the plot, should show average rainfall intensities per 20-minute interval agreeing with the pan data within 1 to 2 percent, at least if a conversion factor is employed.

As to runoff measurement, Sharp has found in field studies that discharge through the Type HS flume is considerably affected by silt deposits on the flume floor. He advises measurement of runoff by weight or volume; or, if the flume must be used, at least it should be protected by a silt trap placed upstream of the flume.

The Intermountain Forest and Range Experiment Station reports that its workers have made a number of improvements in the Type F instrument. By the use of a larger pump, a surge tank, a strong valve and sensitive pressure gages they find that water application can be regulated with satisfactory accuracy. They have abandoned use of the Type HS flume and are measuring runoff by weight, as the weight measurements can be taken just as easily as flume measurements, and with greater accuracy. They measure rainfall by a single run after each infiltration test, using the standard tarpaulin over the plot frame.

Further improvements in this instrument suggested by the Intermountain Station include the addition of more nozzles, equipped with petcocks, to increase the possible range of rainfall intensities and to make it easier to change intensities. They have mounted the sprinkler nozzles on a rigid frame, so that all nozzles are automatically set in the proper position and angle toward the plot when the frame is set in place and properly levelled.

Detailed descriptions of both infiltrometers, as recommended for future use, are given in Appendix A.

EQUIPMENT AND EXPERIMENTAL CONDITIONS

Hydraulic Laboratory

All experiments were conducted indoors, in the hydraulic laboratory of Colorado State College. Ample floor space was provided in a large walled-in area with a concrete floor draining into a long rectangular pit bounding two sides of the floor (Figs. 13 and 14, Appendix A). The whole area was well protected from air disturbances, so that no tents had to be used. Air temperatures varied between 50 and 70 degrees F. during the whole period of study, and rarely fluctuated over 10 degrees during any single experiment. Fort Collins city water was circulated through the infiltrometers from the floor pit; about every third day of tests the whole system was cleaned and flushed out, and the sump was refilled with fresh water. This water is unusually pure, with a mineral content of about 42 parts per million, of which about 17 are calcium carbonate. [4] Water temperatures varied from 44 to 57 degrees F. during the studies; the maximum range in any single experiment was about 7 degrees and the average about 4 degrees.

Infiltrometers

All of this equipment was furnished by the Rocky Mountain and Intermountain Forest and Range Experiment Stations. The instruments and accessories used in the experiments were assembled after considerable discussion

[4] Yearbook of the State of Colorado, 1939-40. p. 487.

and consideration of suggestions obtained from a number of sources. (In Appendix A are presented detailed descriptions, with designs and photographs, of the instruments and accessories employed and recommended for future use.) We should emphasize that the results of these experiments apply strictly to this particular type of equipment, and that any great deviations from the recommended specifications may result in different--probably lowered--accuracy of rainfall application and measurement.

Below are summarized briefly the principal ways in which the Fort Collins infiltrometers may have differed from those in current field use:

Type FA infiltrometer.--We used the Jaeger pump ordinarily employed for the Type F instrument, as the standard Type FA pumping equipment is known to have insufficient capacity to maintain uniform water delivery. A 5-gallon surge tank was placed in the feed line from the pump; flow to the pressure-gage and sprinklers was further regulated by a double valve, with a globe valve for coarse flow regulation and a needle valve for fine adjustment. No water meter was used, as it seems quite generally agreed that discharge through a meter is poorly correlated with variations in rainfall applied to the infiltrometer. The sprinkler nozzles were mounted on a rigid frame which, when properly levelled, placed the nozzles automatically and accurately at their proper position and angle. The plot frame was a one-piece unit, 12x30 inches in dimensions. Recommendations for improvement of this unit are included in Appendix A; also descriptions of all pans and rain-gages tested.

Type F infiltrometer.--The pump was a 4-cylinder Pacific Marine forest fire pump, employed because the standard Jaeger pump is too low in capacity to provide uniform water delivery to this large infiltrometer. A 5-gallon surge tank was installed in the feed line. Twenty-~~eight~~ five sprinkler nozzles were mounted on a rigid, but portable frame, with a stopcock below each nozzle for rapid changes in rainfall intensity. When the applicator frame was installed over the plot, every nozzle was automatically and accurately placed at its proper position and angle. A new type of runoff trough was employed, with its drain pipe arranged to facilitate the weighing of runoff. Runoff water was measured by weight, on a springless balance accurate to 1/10th pound. Other details of this infiltrometer, including rain-gages, are presented in Appendix A.

Each of the instruments and its sprinkler frame were mounted on strong wooden frames, designed to facilitate changing plot slopes. On each frame, the downhill end of the plot was 18 to 20 inches above the floor (Figs. 1 and 14).

With all equipment in good condition; with pure water and small variations in temperature; with complete protection from wind; with the

equipment moved between runs only as much as necessary to change plot slopes; and with trained and careful personnel, the precision of these experiments was probably greater than that ordinarily experienced in field surveys. Relative comparisons between methods of measuring rainfall should, however, be entirely valid; and data on the errors of the various methods should be fairly representative, since a distinct effort was made to simulate field conditions which would be encountered with good equipment and a careful, experienced operating crew.

DESIGN OF THE EXPERIMENTS

Formal Studies

The experimental designs employed in these studies (described briefly in Tables 1a to 15a, Appendix B) were chosen to measure all the desired comparisons and related effects in an unbiased manner, as efficiently as possible; and to provide data on experimental errors as nearly as possible like those encountered in field infiltration studies. Each single observation of rainfall--with the exception of some of the pattern data--was exactly two minutes in length, so as to provide intervals similar to the 1- and 2-minute readings taken in field studies, and long enough to minimize errors of timing. In most of the studies the 2-minute observations were grouped into study units about 1½ hours in length, again so that variations encountered during a unit could resemble those experienced in an infiltration test of average length. In the first study of various rain-pans, for example, three "blocks" of observations were taken, each about 1½ hours long. Each block contained a single 2-minute observation at a low intensity and one at a high rainfall rate for each of six rain-pan conditions (1½- and 3-inch pans; each unprotected, baffled, or screened). With these observations randomized in sequence and spread over a 1½-hour period with the sprinklers operating continuously, each pan condition was equally exposed to any uncontrollable variations in rainfall. Between "blocks" the pump was stopped for an hour or more. Thus the experimental error of this study was based on chance variations as nearly as possible like those encountered in the field; and any significant differences between pan conditions were not only statistically significant, but also of important magnitude from a practical point of view.

Most of the other studies were of the "split-plot" type, with each whole "plot" represented by a single 1½-hour period containing a series of 2-minute measurements. Split-plot designs were admirably adapted to the needs of these experiments; partly because the "plots" could be arranged to fit the desired 1½-hour periods, and partly because, in studies including several plot slopes, the moving of heavy equipment could be reduced to a minimum without sacrificing the requirements of sound design. In the final tests of trough rain-gages on the Type FA instrument (Tables 8 and 8a), for example, we wanted to compare records of rainfall in a screened pan

with records in two trough rain-gages, and to find out how the relation between pan and troughs changed with changes in plot slope and rainfall intensity. A double split-plot design was employed, in which "slope" formed the "major treatment." Each of three plot slopes (5, 20, and 35 percent) was replicated in random sequence. Within each test at a given slope, each of two rain intensities was replicated at random to form the first "split." As a second and final "split," simultaneous 2-minute readings were taken of rainfall in the pan and troughs within each of the 24 slope and intensity tests. With this design, data were provided for unbiased estimates of the variance between pan and trough readings, and of changes in their ratio caused by changes in plot slope and rain intensity. Also, we were able to estimate the effect of changes in plot slope upon the actual amount of rainfall reaching the plot; to ascertain whether this effect of slope varied with rainfall intensity; and to find out whether rainfall rates in repeated runs at the same slope (usually separated by one or more changes of slope) could be duplicated with reasonable accuracy. Appropriate experimental errors were provided for testing all of these comparisons. Finally, from the variances for experimental error and the various interactions could be computed standard deviations expressing the expected error of any single 2-minute reading with the troughs, at any of the plot slopes and rain intensities studied. Thus a wealth of useful information could be obtained from a single, coordinated set of studies occupying less than two days.

Similar designs were employed in testing the reliability of 10-minute pan readings, taken before and after a 1-hour infiltration run, in estimating rainfall actually applied during the run. In these tests, at each intensity and slope eight 2-minute pan (or tarpaulin) readings were taken at 6-minute intervals between the two 10-minute readings, so that the total time occupied by a single complete "run" was about 90 minutes. Assuming straight-line variation between the terminal readings, eight interpolated rainfall rates were computed for comparison with actual rainfall during each intermediate interval, and the resulting data analyzed by the variance method.

Since all of the studies of each type of infiltrometer were conducted in much the same manner, the error variances computed for each method of measuring rainfall could be compared statistically 5/ to find out whether any one method was significantly more accurate than the others.

In some of the experiments with the Type F instrument, the variance of repeated 2-minute readings seemed to increase with rainfall rate. Thus it is possible that different rainfall intensities may sometimes be characterized by different experimental errors; perhaps because the pump may function less reliably at high rates of delivery. If this is true, the computed standard deviations may be a little high for low rain intensities, and low for high rates. It is believed, however, that such variations in error are not to be generally expected; that, if the pump is functioning properly, variations in rainfall per 2-minute interval should not be greatly different at low and high intensities.

5/ By Bartlett's test (Snedecor, Statistical Methods, 1940, p. 206)

Informal Studies

In addition to the experiments discussed above, we made a number of studies which did not require formal design. Such tests included measurements of the amount of rainfall caught directly in the runoff trough of the Type FA instrument; of losses by splashing from the Type F tarpaulin; and of rainfall patterns as affected by factors such as plot slope and rainfall intensity on both instruments.

In measuring rainfall in the Type FA trough, low and high rainfall rates (about 2½ and 4½ inches per hour) were applied to the plot at three slopes. The instrument was supported on a skeleton frame about 18 inches above the floor, and of course no rain pan was used. Measured runoff was converted to inches depth over the whole projected plot area.

For testing splash losses from the Type F tarpaulin, a sheet of coarse (about 12-mesh) muslin was hung over the whole plot as described in Appendix A. Rainfall caught on the protected tarpaulin at two plot slopes and two rain intensities was compared with water caught on the unprotected tarpaulin.

The rainfall pattern measurements were made as described in Appendix C. They were designed to demonstrate how pattern shapes and rainfall distribution are affected by factors such as position of nozzles, rainfall intensity, and slope of plot. All of the tests were made in the laboratory, except those showing the effect of slope on Type FA patterns; these were field data obtained at the Manitou Experimental Forest.

GENERAL EXPERIMENTAL PROCEDURE

With all equipment ready for any desired test, the pump was started and water circulated through the sprinklers until the equipment was saturated and pressures and runoff temperatures were stable. Then 2-minute readings (or longer, as indicated) were taken by the "flying start and stop" method: the collector cans were moved under the drain-spouts and removed after 2 minutes, at signals from a note-taker equipped with a stop-watch. During each test one man attended the control valves, keeping the water pressure exactly at the prescribed number of pounds. Most of the time pressures were pleasingly uniform, requiring little regulation by use of the valves. Runoff temperatures were read and recorded at the end of each 2-minute interval. Between intervals, rainfall rates were changed as called for in each design, by opening or closing nozzle stop-cocks and regulating pressures without stopping the motor. When data were grouped by complete sets as in a randomized-block study, or when plot slope had to be changed, the motor was stopped between complete runs. In changing slopes the whole equipment had to be moved around almost enough to simulate moving from one site to another in the field.

For the Type FA infiltrometer all data on rainfall caught in the pans or rain-gages were recorded in cubic centimeters, using graduates of appropriate capacities, from 25 to 1000 cc. Rain-gage data for the Type F infiltrometer were recorded in cubic centimeters; tarpaulin runoff was measured by weight to the nearest 1/10th pound. All data were converted in the office to rates in inches per hour on the projected area of the infiltrometer. Before and after the experiments with each type of pan or rain-gage, the exact areas of the pans or gages were obtained by careful measurements (Appendix A).

RESULTS [6]

Type FA Infiltrometer

Comparison of unprotected and protected pans of two depths.--In one set of measurements, the pans listed below were tested at low and high rain intensities, with the plot set at a slope of 5 percent (Fig. 1, Appendix A):

1½-inch pan: unprotected; protected with screen; and protected with baffles

3-inch pan; same methods of protection (Fig. 9).

In a second experiment, the 1½-inch pan was protected by means of both screen and baffles (Fig. 10); and compared with the 3-inch baffled pan.

Analyses of the basic data for these studies (Tables 1a and 2a) are shown in Tables 1 and 2; they are interpreted below:

1. Without protection, the 1½-inch pan loses at least 15 to 20 percent of the rainfall applied to it; the 3-inch pan loses at least 10 percent.

2. Either the recommended screen or baffle grid appears to be effective in eliminating splash losses. This result was verified by observations made by holding a dry board above the edge of each pan during the tests. Without protection a heavy collection of water drops was deposited on the under side of the board; with either type of protection only scattered, very fine drops struck the board during a 1-minute period.

3. If the 1½-inch pan is employed, complete protection against splash, even at greater rainfall rates than those studied, is sure to be provided by installing a baffle grid of 1-inch strips above the screen. Incidentally, if the grid and screen are brazed into the pan this arrangement should make a very rigid and durable unit.

[6] For summaries of the original data and brief descriptions of the experiments, see Appendix B; for descriptions of equipment, see Appendix A. Rainfall pattern data are presented in Appendix C.

Methods of measuring rainfall.--Four different methods were tested for measuring rates of water applied to the Type FA infiltrometer:

1. 10-minute readings in the 3-inch screened pan before and after a 1-hour run (Fig. 1).

2. One 10-minute reading in the pan after a 1-hour run. (These results should apply just as well to a single reading before the run).

3. Sampling of rainfall on the plot during a run, by means of ten 1-inch cylindrical rain-cans (Figs. 11 and 12).

4. Sampling of rainfall during the run by means of two 1x30-inch trough rain-gages hung just outside the plot (Fig. 1 and Figs. 5 to 8).

Summaries of the basic data for these studies are shown in Tables 3a, 5a, 6a, 7a, and 8a; their analyses are shown in Tables 3 to 9.

The results are presented below:

1. Pan readings before and after the run (Table 3):

   a. Under optimum conditions this method is as accurate as any of those tested; the standard deviation expressing the error of interpolated values in estimating the true rainfall in any single 2-minute interval was found to be about ± 0.092 inch per hour. With less precise technique, however; with a poorer pump; or as a result of any other complicating factors, this error might easily be much greater.

   b. The error of this method did not vary significantly with rainfall rate.

2. Pan readings taken after each run were decidedly less accurate than the above method (Table 4). The standard deviation was about ± 0.143 inch per hour; by Bartlett's test, significantly greater than the error of readings before and after the run (chi-square = 8.96, with 1 D/F [1]). Again, this error did not vary significantly with rainfall rate.

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[1] With 1 D/F, chi-square must exceed 3.84 to be significant beyond the 0.05 level (odds 19:1); to be significant beyond the 0.01 level, it must be greater than 6.64.

3. Average of ten 1-inch rain-gages (Table 5).--This method is by no means as reliable as the others studied. Even using a conversion factor to correct for consistent deviations of these gages from the true rainfall, the standard deviation expressing the error of a single 2-minute average for the 10 rain-gages is ± 0.198 inch per hour--an error significantly greater than that of any other method tested. Variations in rainfall intensity had no significant effect on the error of this method. We should like to comment that these results are not in conflict with Wilm's earlier findings, as the standard error of a 20-minute average should be only ± 0.063 inch an hour; about 1.6 percent of the average rainfall rates applied in infiltration studies at the Manitou Experimental Forest.

4. The average of readings in two 1x30-inch trough rain-gages seemed to provide the most accurate and generally reliable method for measuring applied rainfall. In comparable experiments (Table 6), the sampling error of the trough rain-gages was not significantly smaller than the error involved in interpolating rainfall from 10-minute pan readings (± 0.078 inch as compared to ± 0.092 inch per hour; chi-square = 0.86, with 1 D/F). Under less precise working conditions, though, the error of interpolated rainfall should increase in proportion to any decreases in precision of technique; on the other hand, the error of the trough gages was relatively unaffected by wide changes in sprinkling conditions.

After preliminary studies had indicated the accuracy of trough gages (Table 6), we made two additional experiments to test them more rigorously. In the first of these, the plot was kept at a slope of 5 percent and all data were taken with 2 nozzles open. Water was delivered at three different pressures, however, (14, 15, and 16 pounds) and the nozzles were tilted toward the plot at two different angles (4 and 7 degrees). The results are shown in Tables 7 and 7a. In Table 7, the "method" interactions are most interesting; they show that, although the trough rain-gages caught significantly less rainfall than the pan (pan ÷ trough = 1.015), the ratio of troughs to pan was not significantly affected by the changes in either pressure or nozzle slope. The standard deviation of the gages in predicting the true rainfall for a 2-minute interval at any of these pressures or nozzle slopes was computed to be ± 0.101 inch per hour; not significantly greater than the error of the first trough-gage study (chi-square = 1.62, with 1 D/F). For comparison with this error, a standard deviation of pan readings was computed to show how much variation in rainfall per 2-minute interval might result from random fluctuations of water pressure between 14 and 16 pounds. This standard deviation, expressing the expected variation of any single pan reading, at any of the three pressures, from the mean of all readings, was ± 0.216 inch per hour. While this figure has

only qualitative value, it indicates how much error may occur in predicting rainfall during an infiltration run from readings before and after the run, if water pressures are permitted to vary materially.

In the final trough-gage test, a single pressure of 15 pounds was employed, with the nozzles set at an angle of 4 degrees toward the plot--this angle, parenthetically, was found to center the rainfall pattern on the plot much better than the standard angle of 7 degrees. This was the split-plot study discussed above under "Design"; the trough-gages were tested at two rain intensities and 3 plot slopes. The results (Table 8) again show the reliability of these trough gages. Although the equipment was moved repeatedly between tests at the different slopes, the relation between pan and trough gages (ratio 1.014) failed to be affected significantly by changes in rain intensity or plot slope, or by repeated measurements at the same intensity or slope. A standard deviation expressing the error of the gages (± 0.121 inch per hour) was significantly larger than that computed in Table 6 (chi-square = 4.50, with 1 D/F); doubtless because the equipment was moved about so much in the final study, and not in the first trough-gage tests. For this reason it is believed that the value of ± 0.121 inch per hour most nearly approximates the field error of trough gages when a single conversion factor is used. Also, even under optimum field conditions, the error of estimating rainfall from initial and terminal pan readings might be expected to approximate at least this figure.

It would be entirely possible to compute a separate conversion factor for the trough gages at any of several rain intensities, or even for several broad classes of plot slope. Since the "method" interactions were not significant, however, the resulting error of the trough readings should not be much reduced (the standard deviation was ± 0.113 inch, using a separate factor for each intensity). Incidentally, we should emphasize that the conversion factors computed in these studies do not necessarily apply to any set of equipment other than the apparatus we employed. On the other hand, we are convinced that the trough-gage error would not be greatly increased if no conversion factor were employed at all; for the data in Table 8, the resulting standard deviation would be about ± 0.151 inch per hour.

Variability of rainfall application with the recommended equipment.--Aside from the comparisons of methods for measuring rainfall, we were able to derive from these experiments, the rainfall pattern tests, and the other informal studies, several informative results showing the magnitude of errors in applying rainfall to the Type FA infiltrometer:

1. Amount of rain caught directly in the runoff trough.--While this factor has no effect on the accuracy of rain-pan measurement of rainfall, it may have a definite influence on measured infiltration rates. In this study (Table 10) the amounts caught varied from 0.047 to 0.143 inch per hour (over the projected area of the whole plot) varying with both slope and intensity of rainfall. Since these amounts are appreciable and cause consistent errors, the Type FA infiltrometer has been redesigned to minimize their occurrence (Figs. 5 to 8; also designs).

2. Consistency of rainfall application.--

a. Most of the variations in applied water occurred during any single 1½-hour period. No significant increase in rainfall variations--between 2-minute intervals--resulted from changes in slope or rainfall rate, or from repeated tests at the same slope or rate. This fact is demonstrated by the similarity among the various mean squares expressing different kinds of sampling error, in Table 8; also by the similarity of rain patterns obtained in the various tests.

b. Marked changes in plot slope had no significant influence on the rainfall received on the projected area of the plot. This result, like all others, applies only to the particular arrangement of sprinklers which we used. Apparently the recommended nozzle arrangement distributes the rainfall uniformly and consistently over the plot at any slope; a result which is indicated in Table 8 and confirmed by study of the pattern data in Appendix C.

c. Although experiments were not designed particularly to test this point, pattern tests indicate that the consistency of rainfall application is just as great with the standard nozzle height and water pressure, as with the arrangement suggested by Sharp. Several pattern tests, made with a pressure of 20 pounds and the nozzles only 12 inches above the plot, indicated that the resulting pattern is poorly shaped, and that its shape is very sensitive to minor variations in nozzle discharge. This second result is rather logical, since the spray travels a relatively great distance from the sprinklers to the plot.

d. With the sprinklers at their standard height and angle toward the plot, the rainfall patterns were uniformly centered over the outside edge of the plot. As a result, the trough gage nearest to the sprinklers consistently caught less rainfall than the outside gage. Besides, most of the raindrops approached the plot at some slope from the vertical. In order to remedy these disadvantages we tried shifting the angle of the nozzles to several different slopes, observing the shape and position of the pattern. We found that the best conditions were obtained by setting the nozzles at a 4-degree angle instead of 7 degrees, with the top of each nozzle four inches (to its center) from the edge of the plot. In this position the sprinklers centered their pattern over the middle of the plot; the two trough gages caught more nearly the same volume of water; and the variability of rainfall caught on the plot was no greater than when the nozzles were in the standard position.

Type F Infiltrometer

Splash losses from the tarpaulin.--After each of the first set of experiments with this instrument at several slopes and rainfall rates, the tarpaulin was covered with muslin and three additional 2-minute readings were taken. The results (Table 11) indicate that little rainfall is lost from the tarpaulin on gentle slopes, and that the losses increase rapidly with slope and rainfall intensity. On a 30-percent slope 0.14 inch per hour was lost at a 2-inch rainfall rate, and 0.33 inch per hour at a 6-inch intensity. Thus, especially on steep slopes, some form of protection must be provided against splash losses. Since most of the splash seemed to pass over the lower end of the plot, such protection might be provided most easily by hanging a light metal shield above both ends of the plot; the uphill shield draining out of the plot, and the downhill one hanging just inside the plot boundary.

Methods of measuring rainfall.--Comparisons of initial and terminal tarpaulin readings with "true" rainfall during 1½-hour runs were made without protection for the tarpaulin, and the first set of trough-gage studies was made under similar conditions. When, however, the splash tests showed material losses, the trough-gage experiments were rerun on a somewhat simplified basis, without replication of plot slopes. The other studies were not repeated, since both the terminal and intra-run tarpaulin data were exposed to the same consistent splash losses and the important comparisons should be entirely valid.

1. Accuracy of 10-minute initial and terminal readings (Tables 12 and 12a). On the whole, this method seems to be one of the most precise of the several methods tested. A standard deviation expressing the error of interpolated rainfall in estimating the true amount per 2-minute interval was ± 0.071 inch per hour; and the predicted rainfall was equally accurate at each of the three slopes and three intensities studied.

2. Accuracy of initial or terminal readings alone (Table 13). In general this method seemed to be just as accurate as the use of initial and terminal readings; the computed standard deviation expressing the error of using terminal readings alone (± 0.061 inch per hour) was not significantly lower than that of the more laborious method (chi-square = 1.70, with 1 D/F). The simpler method is desirable for field use, because of the resulting savings of water and time. For some unexplained reason, though, it showed significant (pooled) interactions with intensity and slope; and this instability of behavior might possibly be reflected in errors of undue size in field studies.

   The error of using initial readings alone was found to be ± 0.081 inch per hour--again not significantly different from the error of initial and final readings. Thus apparently a single reading at either end of an infiltration run may be just as accurate as the use of two terminal readings.

As in the case of the Type FA instrument, the error of any of these methods, involving interpolation or extrapolation of initial and final readings, is doubtless directly related to the precision of operating techniques. If either method is to be as reliable as shown in this study, the equipment must be of equal quality and working procedures must be equally precise.

3. Trough rain-gages. In these analyses, 5 trough gages were studied in three combinations, each compared with readings taken on the cloth-covered tarpaulin. One analysis was based on the average of gages #1 and 5 (outside the plots); a second, on the average of #2 and 4 (bisecting the longitudinal halves of the plot); and a third, on the average of gages #1, 3, and 5 (#3 over the center of the plot).

At first inspection gages #1 and 5 seem to be the most accurate combination (Tables 14 and 14a). The computed standard deviation based on a single correction factor is smaller than those of the other two combinations, and the slope and intensity interactions are not large. Besides, this pair of gages is free of the common objection to having any apparatus hung over the plot. On the other hand, the advantages in precision of this pair may not be real, as the standard deviations for the three gage combinations did not vary significantly among themselves (chi-square = 4.99, with 2 D/F).[8/] Finally, assuming that these three errors are homogeneous, their average was found to be significantly larger than the error of interpolating rainfall from initial and terminal tarpaulin readings (chi-square = 4.36, with 1 D/F).

Consistency of rainfall applied to the plot.--Since Diebold and others have raised some question as to the proper placement and position of the sprinkler nozzles on the Type F infiltrometer, we devoted some time to testing the pattern distributions resulting from the standard nozzle arrangement at three slopes and three intensities. First a large number of preliminary pattern tests were made, during which individual nozzles were exchanged to provide the best possible pattern distribution. In these tests 32 cans were set at 18-inch intervals over the plot (see Appendix A). On the steeper slopes (20 and 30 percent) deficiencies of rainfall at the upper end of the plot occurred when the applicator frame was in its standard position; moved uphill $1\frac{1}{2}$ inches for each percent of slope. These deficiencies seemed to be caused to some extent by lowered pressure at the upper nozzles, but largely by the pattern being centered somewhat downhill of the plot center. They were entirely remedied by moving the frame further uphill, and by attaching the supply hoses at the upper ends of the applicator pipes. Optimum patterns at any slope or intensity were obtained by moving the applicator frame $2\frac{1}{2}$ inches uphill for each percent of slope, with the frame centered over the plot at zero slope.

8/ With 2 D/F, chi-square must exceed 5.99 to be significant beyond the 0.05 level (odds 19:1); or 9.21, to be significant beyond the 0.01 level.

With this final arrangement of the applicator frame, duplicate pattern tests were run at each of three slopes (5, 20, and 30 percent) and three intensities of rainfall (2, 4, and 6 inches per hour, approximately). The results are shown in Appendix C.

Obviously this arrangement of nozzles provided satisfactory patterns, and it should be quite unnecessary to resort to the rather dubious procedure of placing the applicator pipes level or nearly so at any plot slope. Although the patterns varied somewhat at different rainfall intensities, due to the use of different combinations of nozzles, these variations are unavoidable and were not of serious magnitude. Changes in plot slope had no apparent effect on the shape or placement of the rainfall pattern.

Judging from the marked changes in pattern shape caused by exchanging individual nozzles (data not presented), it is very important that tests be made of the pattern thrown by any applicator, before and perhaps once or twice during each field season. These tests need not be formal or complicated; but a number of 5-minute runs should be made at each of several rainfall intensities, and any nozzles producing high or low spots should be exchanged until the pattern is reasonably uniform over the whole plot area at each intensity to be employed.

All of the above tests were, of course, only qualitative in nature, designed only to study the relative distribution of rainfall over the plot. In addition to these results it seemed advisable to find out how variations in slope affected the actual volume of water caught on the projected plot area; and how rainfall volume at each of several intensities varied with slope or with repeated trials at the same slope.

For this analysis, shown in Table 16, two sets of data were available: one with the tarpaulin unscreened, and with slopes and intensities replicated in a split-plot design; the other, with the tarpaulin protected by muslin but without replication of slopes. From the first study could be derived a mean square showing the variance of repeated trials at the same slope, but all comparisons between slopes were influenced by the varying splash losses at different slopes. In the second study, on the other hand, the comparisons between slopes were free of the effects of splash, but no replications of slope were available.

Since in other respects the two studies were quite similar, we were able to combine the valid data from both into a new variance analysis. First each study was analyzed separately (top of Table 16), using only the data on rainfall caught in the tarpaulin (i.e., omitting the trough-gage data). From these variance tables, a pure variance[8a] was computed for each of the significant sources of variation. Finally, these pure variances were used to compute a new variance table (bottom of Table 16), showing the results which should have been expected in a single study, with the tarpaulin protected and slopes replicated.

8a/ See Wilson, C. P., & G. L. Clarke. - A statistical study of variation in the catch of plankton nets. Journal of Marine Research, Vol. III, No. 1, pp. 1-34. May 1, 1940.

We realize that the results of such a synthesis must be taken with some conservatism. Since, however, the "between slopes" mean square was actually smaller than "within slopes," and since none of the interactions was larger than their experimental error, we are confident that there exists no real effect of plot slope on the rainfall caught by the plot at any of the three rain intensities.

Results and CONCLUSIONS

Type FA Infiltrometer

1. With the recommended equipment (Appendix A) rainfall volume and pattern shape are regulated with satisfactory accuracy, even on different plot slopes and at different rates of artificial rainfall. Water pressures can be kept without difficulty at the prescribed number of pounds; and the position, height, and angle of the nozzles are accurately controlled by a new sprinkler frame. In a newly designed infiltrometer frame, errors due to splash and to rain falling directly into the runoff trough are minimized.

   a. The rainfall pattern is centered over the plot when the nozzles are mounted 30 inches above the soil and four inches away from the infiltrometer frame, and tilted toward it at an angle of 4 degrees. In the other plane the nozzles should be kept vertical--not normal to the plot slope. This is accomplished simply by mounting each nozzle in a street-ell.

   b. In order to obtain results as accurate as those found in our experiments, the recommended specifications for equipment should be closely followed.

2. The use of a pair of 1"x30" trough rain-gages, hung outside the plot (Appendix A), for sampling rainfall should be at least as accurate as the standard method using 10-minute readings before and after an infiltration run. Under laboratory conditions the two methods are of equal accuracy; the reliability of the trough gages, however, is little affected by wide changes in water pressure, nozzle slope, or other factors, whereas the error of the other method should vary directly with any reductions in precision of operating technique. Incidentally, with the trough gages no time and water are needed for initial and terminal readings.

3. A single 10-minute reading taken before or after an infiltration run provides rainfall estimates much less accurate than either trough-gage data or initial and terminal readings.

4. Ten 1-inch cylindrical rain-cans fail to provide a sufficiently accurate sample of rainfall; the error of their average is significantly greater than the errors of either of the two recommended methods.

5. With either of the two best methods, under optimum conditions a standard deviation expressing the variation of any single 2-minute reading from the true rainfall should be about ± 0.08 to 0.13 inch per hour at any plot slope or rain intensity. Thus about one reading out of 20 will deviate from the true rainfall by ± 0.16 to 0.26 inch per hour.

   a. This amount of error is associated with uncontrollable, short-period variations in rainfall applied to the plot. Even though initial and terminal readings may be identical, intermediate readings (per 2 minutes) may vary more or less at random over a considerable range; even with the water pressures held exactly at 15 pounds.

6. If initial and terminal pan readings are used, the pan should be protected against splash losses. In a pan 3 inches deep, such protection is adequately furnished by either a screen or a baffle grid (Appendix A); in a 1½-inch pan complete protection is provided by a combination of screen and baffles. An unprotected 1½-inch pan will lose about 20% of applied rainfall.

Type F Infiltrometer

1. If the recommended specifications for this equipment and its use are followed, rainfall can be controlled with satisfactory accuracy, and its distribution and volume are relatively unaffected by large changes in plot slope.

   a. The tarpaulin and plot should be protected against splash losses, especially on steep slopes.

   b. Rainfall and runoff volumes may be accurately and rapidly measured by weight.

2. Ten-minute initial and terminal readings on the screened tarpaulin provide the most accurate method of estimating rainfall applied during an infiltration test; and either initial or terminal readings alone seem to be just as accurate as the use of both together. These conclusions may apply only if the field technique is at least as precise as our laboratory technique.

a. Under our conditions the standard deviation of the difference between the estimated and true rainfall per 2-minute interval is about ± 0.06 to 0.08 inch per hour--somewhat lower than the corresponding error for the Type FA infiltrometer. The smaller error is probably associated more with plot size and number of nozzles than with the higher water pressure.

3. Of the three combinations of trough-gages which were tested, the best results seem to be provided by two gages hung just outside the longitudinal boundaries of the plot. Under laboratory conditions the error of this or any of the other trough-gages is somewhat larger than that associated with tarpaulin readings. In the field, however, the trough-gages may often prove to be the most reliable method of estimating rainfall on the plot.

In considering the results of these studies, the reader may wonder whether the unavoidable errors of even the best of equipment and methods of measuring rainfall are undesirably large: whether they would constitute an important part of the experimental error of any infiltration study. This question may be worth a little discussion.

Field data have shown that in general the coefficient of variation of a single average minimum infiltration capacity (f_c) in any single cover type will vary between 25 and 60 percent of the average "f_c" value. Assuming that it will average 40 percent of an average "f_c" value of 0.50 inch per hour, the variance expressing this variation is 0.0400 (i.e., the square of ± 0.20 inch per hour). Now, if each "f_c" value was based on the final 12 minutes of each infiltration run and if the standard deviation of rainfall measurements is assumed to be about ± 0.12 inch per hour, then a variance expressing the error of the average rainfall is about 0.0024 (i.e., $(0.12)^2 \div 6$)--about 6 percent of the variance of the "f_c" values. This amount is so small that it would certainly not be worth while to attempt its reduction by further improvement of instrumental techniques, unless such improvements required less than 6 percent additional investment in equipment and personnel time.

Table 1.--Comparison of pans for measuring rainfall applied to the Type FA infiltrometer

Analysis of variance

Source of variation	D/F	Mean square	F 1/
Total	35		
Between means of "blocks"	2	0.00280	<1.00
Blocks x conditions tested (exp. error)	22	0.01223	
Between conditions tested, broken down into 11 comparisons:	(11)		
Low vs. high intensity, all pans	1	16.96067	1386.8
1½-inch pan vs. 3-inch pan, low intensity	1	0.03920	3.21
" " " " " high "	1	0.18605	15.21
Screen vs. baffle, 1½-inch pan, low "	1	0.00482	<1.00
" " " " " high"	1	0.06615	5.41
" " " 3-inch pan, low "	1	0.00960	<1.00
" " " " " high"	1	0.00282	<1.00
Unprot. vs. protected, 1½-inch pan, low int.	1	0.22894	18.72
" " " " " high "	1	1.36125	111.30
" " " 3-inch " low "	1	0.12836	10.50
" " " " " high "	1	0.41405	33.86

1/ "F" = ratio of each mean square to the error mean square. If any "F" value in this column is greater than 4.30 (D/F = 22 and 1), the odds are greater than 19:1 that the tested difference is larger than might occur purely by chance. If the "F" value is greater than 7.94, the odds are greater than 99:1.

Table 2.--Comparison of rain pans: screened and baffled $1\frac{1}{2}$-inch pan compared with baffled 3-inch pan.

Type FA infiltrometer
Analysis of variance

Source of variation	D/F	Mean square	F
Total	15		
(1) Between intensities	1	23.0880	
(2) Within intensities	6	0.0035	
(3) Between methods	1	0.0081	2.19
Interactions:			
(1)x(3)	1	0.0182	4.92
(2)x(3) (error for methods)	6	0.0037	

Table 3.--Comparison of 2-minute pan readings of rainfall (in screened 3-inch pan) with data from 10-minute readings before and after each 1-hour run

Type FA infiltrometer (5% slope)

Analysis of variance

Source of variation	D/F	Mean square	F
Total	95		
(1) Between rain intensities	1	35.77041	134.6^{xx}
(2) Within " " (error for "1")	4	0.26584	
(3) Between intervals within intensities	42	0.01091	3.67^{xx}
(4) Between methods	1	0.03450	3.77
Interactions: (1)x(4)	1	0.00844	--
(2)x(4) (error for "4"and "1x4")	4	0.00914	3.08^{x}
(3)x(4) (error for testing "3" and "2x4")	42	0.00297	

^{x}Significant ($p. < 0.05$)

^{xx}Highly significant ($p. < 0.01$)

The error involved in interpolating rainfall data from 10-minute pan readings before and after a 1-hour infiltration run, to estimate the true rainfall during any single 2-minute period, may be expressed by the standard deviation $s = \pm 0.092$ inch per hour.

Table 4.--Comparison of 2-minute pan readings of rainfall with 10-minute readings taken after each 1-hour run

Type FA infiltrometer

Analysis of variance

Source of variation	D/F	Mean square	F
Between methods	1	0.0290	--
Methods x intensities	1	0.1388	3.73
Methods x within intensities (error)	4	0.0372	8.86 **
Methods x intervals within intensities (sampling error)	42	0.0042	

**Highly significant (p. <0.01)

The standard deviation of the difference between estimated and true rainfall for any single 2-minute observation is ± 0.142 in./hr. See table 3a for basic data.

Table 5.--Variance of rainfall measured in ten 1-inch rain cans, as compared to rain-pan data

Type FA infiltrometer (5% slope)

Source of variation	D/f	Mean square	F
Total	47	0.49716	
(1) Between intensities	1	19.40563	317.1 **
(2) Within intensities (error for (1))	4	0.06119	
(3) Between methods	1	2.49341	77.1 **
Interactions:			
(1)x(3)	1	0.06021	1.86
(2)x(3) (error for "3"+"1x3")	4	0.03234	2.212
(4) Between intervals within intensities	18	0.04278	2.93*
Interaction:			
(3)x(4) (error for testing (2)x(3) and (4))	18	0.01462	

*Significant (p. <0.05)
**Highly significant (p. <0.01)

Using a single conversion factor for both rain intensities, the standard deviation expressing the error of a single 2-minute reading with these 10 cans (as compared to the pan reading) is ± 0.198 inch per hour. The conversion factor in this study (from can average to true rainfall) is 0.881.

Table 6.--Comparison of rainfall in screened pan with rain measured in two 1-inch trough gages

Type FA infiltrometer (on 5% slope)

Analysis of variance

Source of variation	D/F	Mean square	F
Total	47		
(1) Between rain intersities	1	18.01975	180.6 **
(2) Within intensities (error for "1")	4	0.09976	
(3) Between pan and troughs	1	0.00035	---
Interactions:			
(1)x(3)	1	0.00585	2.95
(2)x(3)(error for "3" and "1x3")	4	0.00198	---
(4) Between intervals within intensities	18	0.01894	5.86 **
Interaction:			
(3)x(4) (error for "2x3" and "4")	18	0.00323	

** Highly significant ($p. < 0.01$)

Standard deviation of the difference between a single 2-minute trough reading and the rainfall in the pan = $\pm$ 0.078 inch per hour. (At either intensity, using no conversion factor from trough average to true rainfall.)

Table 7.--Comparison of rainfall in 3-inch screened pan with rain measured in two 1-inch trough gages: test of effect of variation in nozzle slope and water pressure

Type FA infiltrometer (on 5% slope)

Analysis of variance

Source of variation	D/F	Mean square	F
Total	47		
Between means of:			
(1) Pressures (14,15,16#)	2	0.5924	76.9 **
(2) Nozzle slopes (4 and 7°)	1	4.8324	627.6 **
(1)x(2)	2	0.0109	1.42
Within (error #1)	18	0.0077	
(3) Between pan and trough	1	0.0475	8.64 **
Interactions:			
(1)x(3)	2	0.0014	--
(2)x(3)	1	0.0116	2.11
(1)x(2)x(3)	2	0.0023	--
(3) x"within" (error #2)	18	0.0055	

**Highly significant ($p. < 0.01$)

The standard deviation of the difference between a single 2-minute reading in the troughs and the rain caught in the pan is $\pm$ 0.101 inch, if a single conversion factor is used for any pressure or nozzle slope. This factor, for converting troughs to pan data, is 1.014. If no conversion factor is used, the standard deviation should be about $\pm$ 0.118 inch per hour.

If the pan were used alone for predicting rainfall (as before and after an infiltration run) and any of the 3 pressures might occur at random, the standard deviation of any single 2-minute reading would be about $\pm$0.216 inch per hour.

Table 8.--Final tests of two 1-inch trough rain-gages, compared with rainfall in 3-inch screened pan

Type FA infiltrometer

Analysis of variance

Source of variation	D/F	Mean square	F
Total	47		
(1) Between slopes (5,20,35%)	2	0.002534	--
(2) Within slopes (error for testing "1")	3	0.004845	
(3) Between rain intensities	1	5.555602	99.9 **
Interactions:			
(1)x(3)	2	0.078808	1.42
(2)x(3) (error for "3" and "1x3")	3	0.055667	
(4) Within intensities and slope	12	0.010144	
(5) Between troughs and pan	1	0.036852	5.17 *
Interactions:			
(1)x(5)	2	0.000833	--
(3)x(5)	1	0.029502	4.14
(1)x(3)x(5)	2	0.005059	--
(2)x(5) + (4)x(5) + (2)x(3)x(5): error for testing terms containing (5)	18	0.007123	

*Significant ($p. < 0.05$)
**Highly significant ($p. < 0.01$)

If a single correction factor is used for the trough gages at any slope or rain intensity, the error of a single 2-minute reading with the troughs (measured from the pan readings) is $\pm$ 0.121 inch per hour. If a separate factor were used for each intensity, the corresponding error should be about $\pm$ 0.113 inch per hour. If no conversion factor were used, the error would be approximately $\pm$ 0.131 inch per hour.

Table 9.--Errors of several methods of measuring rainfall

Type FA infiltrometer

Method	D/F	Error variance [1]	Standard deviation [2]	Conversion factors used
			In./hr, ±	
1. Interpolation from 10-minute pan data before and after a 1-hour run (2 intensities, 5% slope of plot)	48	0.00850	0.092	None
2. Interpolation from 10-minute pan data after a 1-hour run	48	0.02054	0.143	None
3. Average of 10 1-inch rain cans over infiltrometer (2 intensities, 5% slope)	23	0.03936	0.198	0.881 [3]
4. Average of 2 trough gages hung along sides of instrument):				
(a) At 2 intensities, 5% slope	24	0.00602	0.078	None
(b) Using 1 or 2 nozzles, at pressures of 14, 15, & 16#, and with nozzle at 4° and 7° slopes	23	0.01030	0.101	1.015 [3]
(c) (Final tests): pressure 15#, nozzles 4° slope; 2 intensities; 3 plot slopes	23	0.01474	0.121	1.014 [3]

1/ Built up from pure variances associated with each component of variation.
2/ Expressing the probable variation of any single 2-minute reading by each method, from the true rainfall as measured in a 3-inch screened pan.
3/ Average factor used for any intensity.

By Bartlett's test for homogeneity of errors, the error of method #2 is greater than that of method #1; method #1 is not more precise than method #4 (based on #4a); and #4c shows more error than #4a.

Table 10.--Type FA infiltrometer: Amount of rainfall caught directly in runoff trough, on three slopes

Rain intensity	Slope of plot, percent								
	5			15			25		
	Rain	Runoff		Rain	Runoff		Rain	Runoff	
	In./hr.	In./hr.	%	In./hr.	In./hr.	%	In./hr.	In./hr.	%
Low	2.42	0.047	1.94	2.01	0.057	2.84	2.18	0.096	4.40
	2.46	0.045	1.83	2.10	0.070	3.33	2.15	0.094	4.37
Ave.			1.88			3.09			4.39
High	4.54	0.059	1.30	4.51	0.099	2.20	4.41	0.143	3.24
	4.54	0.057	1.26	4.68	0.103	2.20	4.35	0.134	3.08
Ave.			1.28			2.20			3.16

Table 11.--Rainfall caught on tarpaulin with and without cloth screen

Type F infiltrometer

Slope	Rainfall intensity						
	Low			High			Average
Percent	Screen (In./hour)	None	Loss %	Screen (In./hour)	None	Loss %	Loss %
5	2.08	2.12	--	5.68	5.63	1.0	0.0
30	2.13	1.99	6.6	5.76	5.43	5.7	6.0

Table 12.--Comparison of rainfall interpolated from 10-minute readings before and after each 1-hour run, with rainfall measured during intervening 2-minute intervals

Type F Infiltrometer

Analysis of variance

Source of variation	D/F	Mean square	F
Total	143		
Between means of:			
(1) Intensities (2,4,& 6" /hr.)	2	150.90205)	no error term
(2) Slopes (5,20,& 30%)	2	0.34960)	available
(3) Intervals within intensities and slopes	63	0.00146	
(4) Methods (10-min. vs. 2-min.)	1	0.00667	2.84
Interactions:			
(1)x(2)	4	0.02084	no error term available
(1)x(4))	2)	0.00484)	1.95
(2)x(4))error for testing	2)8	0.00330)0.00235	1.33
(1)x(2)x(4)) "methods"	4)	0.00063)	--
(3)x(4) (error for testing interactions containing "methods")	63	0.00248	

The standard deviation of interpolated rainfall from the actual amount reaching the infiltrometer in any 2-minute interval, on any slope or at any intensity, is ± 0.071 inch per hour. No conversion factor can, of course, be used.

Table 13.--Comparison of rainfall estimated from a single 10-minute reading following each 1-hour run, with rainfall measured during 2-minute intervals within each run

Type F infiltrometers

Analysis of variance

Source of variation	D/F	Mean square	F
Methods (estimated vs. actual)	1	0.00902	--
Interactions:			
Methods x intensities)	2)	0.00227)	
Methods x slopes)	2)8	0.00290)0.01454	9.96 **
Triple)	4)	0.02650)	
(experimental error for testing methods)			
Methods x intervals within intensities and slopes	63	0.00146	

**Highly significant ($p. < 0.01$)

The standard deviation of estimated from actual rainfall per 2-minute interval is ± 0.061 inch per hour. No conversion factor can be used. See Table 12a for basic data.

Table 14.--Comparison of trough gage records with rainfall in tarpaulin (protected from splash)

Type F infiltrometer

A. Analyses of variance

Source of variation	D/F	Mean squares: Gages 1/ 1 & 5	Gages 2 & 4	Gages 1, 3, & 5
Total	53			
(1) Between slopes	2	0.0136	0.0798	0.0469
(2) Between intensities	2	50.8164	52.8170	52.7552
(1)x(2)	4	0.0066	0.0100	0.0051
(3) Within intensities & slopes	18	0.0046	0.0071	0.0049
(4) Between methods	1	0.1014**	0.5281*	0.4667**
(1)x(4)	2	0.0032	0.0275*	0.0136*
(2)x(4)	2	0.0108	0.0330*	0.0314**
(1)x(2)x(4)	4	0.0068**	0.0032**	0.0009
(3)x(4)	18	0.0011	0.0007	0.0004

B. Conversion factors (troughs to tarpaulin)

Intensity			
2",4", or 6"	0.978	0.950	0.953
2"	0.958	0.952	0.951
4"	0.991	0.948	0.956
6"	0.976	0.952	0.952

C. Standard deviations of the differences between any single 2-minute reading with trough gages and the true rainfall (all in inches per hour)

1) Single conversion factor:	± 0.078	± 0.122	± 0.104
2) Separate factor for each intensity:	± 0.078	± 0.092	± 0.063

*Significant ($p. < 0.05$)

**Highly significant ($p. < 0.01$). In testing "methods", interactions "1x4" and "2x4" were pooled for use as the error term.

1/ Trough gages 1½" x 12.0 ft. hung lengthwise over the plot; #1 and 5 just outside and above the boundaries; #2 and 4 bisecting each plot half; and #3 bisecting the whole plot.

Table 15.--Relative errors of several methods of measuring rainfall

Type F infiltrometer

Method	D/F	Error variance [1]	Standard deviation [2] ±	Conversion factor used
1. Estimation of rainfall from 10-min. readings before and after a 1-hr. run	72	0.00504	0.071	None
2. Estimation of rainfall from one 10-min. reading after a 1-hr. run	72	0.00370	0.061	None
3. Average of two trough gages, using gages Nos.:				
(a) 1 and 5	26	0.00610	0.078	0.978 [3]
(b) 2 and 4	26	0.01500	0.122	0.950 [3]
(c) 1, 3, and 5	26	0.01074	0.104	0.953 [3]

[1] Built up from pure variances associated with each component of variation.

[2] Expressing the probable variation of any single 2-minute reading by each method, from the true rainfall as measured in the tarpaulin.

[3] Using a single conversion factor for any intensity or slope.

Table 16.--Effect of plot slope on rainfall recorded on Type F infiltrometer

Analyses of variance

Source of variation	D/F	Tarpaulin screened		Tarpaulin unscreened	
		Sums of squares	Mean squares	Sums of squares (35 D/F)	Mean squares
Total	26	50.31767	1.93530	64.64203	1.84692
(1) Between slopes	2	0.02676	0.01338	0.73627	0.36814
(2) Within slopes (error for slopes)	3	- -	- -	0.11868	0.03956
(3) Between intensities	2	50.22969	25.11484	63.46602	31.73301
(1)x(3)	4	0.00722	0.00180	0.13162	0.03290
(2)x(3)	6	- -	- -	0.03349	0.00558
(4) Within intensities and slopes	18	0.05400	0.00300	0.15595	0.00867

Synthesized analysis, based on pure variance:

Pure variances are:

1) derived from study with screened tarpaulin: $s_1^2 = 0.00117$; $s_3^2 = 2.79023$; $s_4^2 = 0.00278$; the interactions are zero.

2) derived from study with unscreened tarpaulin: $s_2^2 = 0.00352$

Assuming 36 observations set up like the "unscreened" study, with "slopes" replicated, but with tarpaulin screened; the analysis of variance should give the following results:

Source of variation	D/F	Contains:	Mean square	F
(1) Between slopes	2	$12s_1^2 + s_4^2$	= 0.01682	<1.00
(2) Within slopes (error #1)	3	$9s_2^2 + s_4^2$	= 0.03446	
(3) Between intensities	2	$12s_3^2 + s_4^2$	= 33.48554	12,045 **
(1)x(3)	4	$4s_{13}^2 + s_4^2$	= 0.00278	1.00
(2)x(3)	6	$3s_{23}^2 + s_4^2$	= 0.00278	1.00
(4) Within intensities and slopes (error #2)	18	s_4^2	= 0.00278	

**Highly significant ($p. < 0.01$)